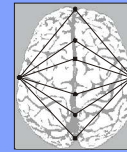
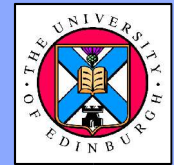


Extracting Motion Primitives from Natural Handwriting Data

Ben Williams



Neuroinformatics
Doctoral Training Centre



Biological Background

Bizzi *et al* (1995) showed that the motor control of the frog's leg was modular in operation, by stimulating different areas on the spine, and analysing the force produced by the leg.

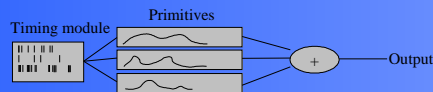
Wolpert *et al* (1998) hypothesise that motor control and internal models are partitioned into output units, modelling a specific part of a movement, and can overlap with each other, creating a segmented overall model.

Gallese *et al* (1996) discover the existence of action selective mirror neurons in the premotor cortex, showing that groups of neurons could be representing a single type of movement, both in terms of action and recognition.

Motor Primitives

The superposition of movements implies an underlying modularisation of motor control. This can be generalised by a Piano Model.

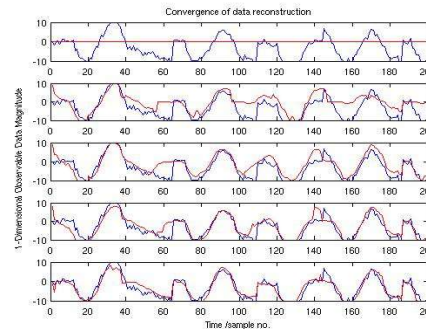
$$Y(t) = \sum_{(i,j)} \alpha_{(i,j)} z_i(t - \tau_{(ij)})$$



Each $z_i(t)$ is a primitive. There are i primitives, each triggered j times within the sample window.

Robotics

Teaching robots how to perform even simple tasks is a complex problem that humans accomplish simply by imitating others. Imitation learning could be a way for a robot to learn a movement without having to solve all the control dynamics equations. Similarly, children learn how to write by copying examples from the teacher. However varied styles of handwriting arise from the same training set. This suggests that motor learning is only flexible up to a point, which could be dictated by the motor primitives.



Reconstruction using EM algorithm on a fHMM

fHMMs are more representative of the Piano Model framework than ICA. However, inferring the parameters for the model is difficult, and is explored by Ghahramani *et al* (1997). The Expectation Maximisation algorithm can provide local optimisation, and with the appropriate constraints, can infer the original primitives from a dummy data set. Here we can see the reconstruction of the data in red, and the original data in blue, demonstrating the iterative convergence of the algorithm.



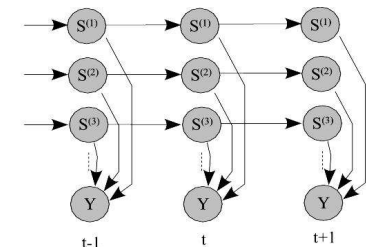
ICA vs. fHMM

Thinking of the motor primitives as independent sources generating the data instantly suggests using ICA to separate them out. However, ICA does not take into account timing information. This means that, when taking datums as time extended chunks, without exact primitive timing information, the data is non-stationary across dimensions from the point of view of ICA. To resolve this, a closer representation of the Piano Model is needed.

A Factorial Hidden Markov model takes each observable time slice as the weighted combination of output means from an array of independently evolving hidden states, with only local time dependence on state evolution. This is very similar to the Piano Model, with the only differences being that the state transition probabilities are heavily constrained in the Piano Model, and that the Piano Model assumes a baseline output that is representative of none of the primitives being active.

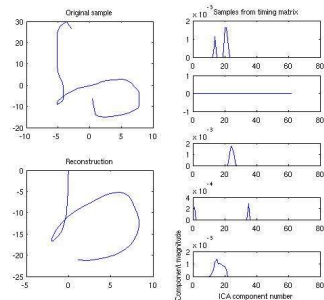
Factorial Hidden Markov Model

A graphical representation of a fHMM shows that the output is only dependent upon the hidden states at any one time step, and that the hidden states evolve separately.



References

- Bizzi *et al* (1995) Modular organization of motor behavior in the frog's spinal cord. *Trends in Neurosciences*, 18(10):442-446
- Gallese *et al* (1996) Action recognition in the premotor cortex. *Brain*, 119:593-609
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- Wolpert *et al* (1998) Multiple paired forward and inverse models for motor control. *Neural Networks*, 11:1317-1329



Reconstruction algorithm using possible motor primitives

Using primitives from a sliding window ICA approach, a simple closest fit reconstruction algorithm can produce characters that resemble a child's attempt at writing.